# Stale Seedbed Techniques for Organic Vegetable Production<sup>1</sup>

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**Abstract:** Weed control in organic vegetable production systems is challenging and accounts for a large portion of production costs. Six methods to prepare a stale seedbed were compared on certified and transitional organic land in Salinas, CA, in 2004. Weed control operations occurred on raised beds 2 to 3 d before planting baby spinach or a simulated vegetable planting. A flamer and an herbicide application of 10% v/v of a clove oil mixture (45% v/v clove oil) at 280 L/ha (iteration 1) or 15% v/v of a clove oil mixture (45% clove oil) at 467 L/ha (iterations 2 and 3) were used to control weeds without disturbing the soil. Top knives on a sled, a rolling cultivator, and a rotary hoe were used to control weeds while tilling the bed top. A bed shaper-rototiller combination was also used, which tilled the entire bed. Broadleaf weed control was 36% with clove oil, 63% with the rotary hoe, and significantly higher (87 to 100% control) with the remaining treatments in iteration 1. Broadleaf weed control was consistently lower (72 to 86%) control) with the flamer than all other treatments (95 to 100% control) in iterations 2 and 3. The difference between sites can probably be attributed to differences in weed size. The flamer and the clove oil herbicide had the lowest number of weeds emerging with the crop following stale seedbed formation. The most expensive technique was clove oil at \$1,372/ha. The estimated cost of forming the stale seedbed with the remaining weed management tools ranged from \$10 to

Nomenclature: Spinach, Spinacia oleracea L. #3 SPQOL.

**Additional index words:** Flaming, cultivation, weed emergence, irrigation, stale seedbeds, vegetables.

Abbreviations: USDA-ARS, U.S. Department of Agriculture–Agricultural Research Service.

## INTRODUCTION

California is a major source of fresh market, leafy vegetables for the United States. In 2004, 11,331 ha of fresh market spinach were grown in California with a value of \$199.9 million (NASS 2005). The total production of fresh market spinach in the United States is 16,430 ha valued at \$245 million (NASS 2005). Fresh market spinach and mesculin, a mixture of mostly immature leaves of various species sold as salad mixes, are grown in high-density plantings on raised beds. Weed management for organic production of these crops typically includes tillage, crop rotation, and stale seedbeds. Mechanical weed control

A stale seedbed is a seedbed where the nondormant weeds in the germination zone (shallow soil layers from which weeds can emerge) are killed before crop planting. Weed emergence from the germination zone depends on weed species, soil type, tillage, and soil physical characteristics (Buhler and Mester, 1991; Mohler and Galford, 1997; Yenish et al., 1996). Most weeds in arable fields emerge from the top 6 cm of the soil profile (Cousens and Moss, 1990; du Croix Sissons et al., 2000). Therefore, stale seedbed formation is successful when most of the nondormant weeds in the top 6 cm of the soil profile emerge and are killed before crop planting. The depleted weed seed bank in the germination zone reduces weed pressure in the crop.

following crop emergence is not typically possible because of high crop density (5 to 7 million plants ha<sup>-1</sup>). Consequently, hand-weeding is the only weed control method available after the crop emerges. Stale seedbeds are one weed management option that has the potential to reduce hand-labor and weed management costs in spinach and mesculin crops.

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<sup>&</sup>lt;sup>3</sup>Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised, 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

A variety of techniques may be used to form a stale seedbed. Theoretically, the most effective techniques should minimize soil disturbance and the movement of seeds from deep in the soil profile into the germination zone. Techniques, such as herbicides and flamers that do not disturb the soil, should minimize weed emergence following stale seedbed formation. Caldwell and Mohler (2001) used flaming or glyphosate applications to form stale seedbeds and significantly reduced broadleaf weed density and biomass. The treatments only partially controlled the weeds, and the authors suggest that these weed removal techniques could be incorporated into an integrated weed management system.

Many shallow tillage implements may also be used effectively to create stale seedbeds. Johnson and Mullinix (2000) reported no difference in the weed removal efficacy of a power tiller, disk harrow, field conditioner, and sweep cultivator. However, they found that peanut (*Arachis hypogaea* L.) yields tended to be higher with shallow tillage than techniques with no tillage. Johnson and Mullinix (1995, 1998) also found that shallow cultivation was more effective than glyphosate for stale seedbed preparation in cucumbers (*Cucumis sativus* L.) and peanuts.

The study objective was to compare the weed control potential of several stale seedbed techniques for organic vegetable production. Techniques ranged from zero to high soil disturbance. We hypothesized that fewer weeds would emerge during the cropping season when weeds were controlled without disturbing the soil than with soil disturbance.

## **MATERIALS AND METHODS**

Three iterations of a stale seedbed experiment were conducted in 2004 on certified or transitional organic U.S. Department of Agriculture–Agricultural Research Service (USDA-ARS) land. Iteration 1 occurred in the summer at the USDA-ARS research farm in Salinas, CA. Iterations 2 and 3 occurred in the fall at the USDA-ARS research station in Salinas, CA and USDA-ARS research farm, respectively. The soil at site 1 (iteration 1 and 3) was a Chualar series, loamy sand, and the soil at site 2 (iteration 2) was a Chualar series loam. The fields were cover-cropped the previous winter (October to February), and the cover crops were incorporated in the spring and left fallow until the beginning of the experiment. A rototiller–bed shaper combination implement was

used to form flat, smooth, 2-m-wide beds (center to center) before the beginning of the experiment.

The experimental design was a randomized complete block with six treatments and four replicates repeated over three iterations. Plots were 4 m wide at all iterations and covered one full bed in the middle with half a bed on both sides. All measurements were taken from the full, middle bed. Plots were 76, 24, and 30 m long at iterations 1, 2, and 3 respectively. Iterations 1, 2, and 3 received 7.6 cm of sprinkle irrigation at the beginning of the experiment, spread over several days between July 7 and 21, September 9 and 16, and September 13 and 20, respectively.

The six techniques were tested for forming stale seedbeds on July 26 in iteration 1, September 20 in iteration 2, and September 28 in iteration 3. A tractormounted propane flamer using 24 kg/ha of propane with six burners per 2-m bed top was used to control weeds without disturbing the soil. Propane usage was estimated by measuring the quantity of propane required to refill the tank following 15 min of burning. A 10% v/v clove oil mixture4 at 280 L/ha (iteration 1) or 15% v/v clove oil mixture at 467 L/ha (iteration 2 and 3) applied with a custom-made, tractor-mounted sprayer was also used to control weeds without disturbing the soil. The clove oil spray mix included a humic acid surfactant (0.01% humic acid derived from leonardite)<sup>5</sup> at 0.25% (v/v). Top knives arranged on a sled, a rolling cultivator,6 and a rotary hoe<sup>7</sup> were used to remove weeds from the bed top. The top knives disturbed the top 4 to 5 cm of the soil, whereas the rolling cultivator and rotary hoe disturbed the top 8 to 9 cm of soil. The rototiller-bed shaper combination implement tilled the bed thoroughly. A single pass was used for all techniques, except the rotary hoe, where two consecutive passes in opposite directions were used. Preplant weed removal occurred when weeds were at the two- to four-leaf stage at iteration 1 and the cotyledon to one-leaf stage at iterations 2 and 3.

Emerged weeds were identified and counted by species in 4, 0.25-m<sup>2</sup> quadrats 1 d before weed management treatments, 1 to 2 d after weed management treatments, and at least 15 d after spinach

<sup>&</sup>lt;sup>4</sup>Matran 2, EcoSmart Technologies, 318 Seaboard Lane, Suite 208, Franklin TN 37067.

<sup>&</sup>lt;sup>5</sup>Integrate, The Catalyst Product Group, 26201 West Baseline Road, Buckeye, AZ 85326.

<sup>&</sup>lt;sup>6</sup> Lillistion, Bigham Brothers Inc., 705 East Slaton Road, Lubbock, TX 79452

<sup>&</sup>lt;sup>7</sup>Yetter Farm Equipment, 109 South McDonough, Colchester, IL 62326.

planting (iterations 1 and 3) or simulated vegetable planting (iteration 2). Only live weeds were included in the before and after planting weed counts.

Thirty rows of baby spinach were planted on the bed tops of iterations 1 and 3. The spinach planter included a chain that dragged on the soil surface causing shallow disturbance across the bed top. The spinach in iterations 1 and 3 was irrigated as needed for growth. Vegetable planting was simulated in iteration 2 by driving an empty vegetable seeder with five seeder shoes over the bed tops. This seeder did not have a chain on it and disturbance was only created in rows where the seeds would have been deposited. The irrigation regime (time between applications and application rates) was similar in iterations 2 and 3.

Estimated cost of stale seedbed treatments was calculated using information derived from cost-return studies produced at the University of California, Davis (Tourte et al. 2004). The hours per hectare for each treatment were calculated based on tractor speed and implement width. The costs of the clove oil and Integrate mix were based on the concentration applied per hectare and the current cost of the materials (Matran II at \$72.35/gal mixed with Integrate at \$19.50/gal). The cost of propane was calculated by multiplying the current cost (\$1.63/gal) of propane by the usage rate. Propane use was estimated by filling the propane tank, running the propane burner for 15 min, then refilling the propane tank to determine the amount consumed. The costs of running and owning the equipment were based on estimates from cost-return studies from the University of California, Davis. The labor cost was based on the average salary paid for a tractor operator multiplied by the time required to cover a hectare.

Data were analyzed initially using PROC MIXED in SAS,<sup>8</sup> with iteration and block as random effects. The treatment effects differed among iterations, and the data for each iteration were thus analyzed separately using PROC MIXED. Control of individual weed species was also analyzed with PROC MIXED. Weed emergence within the spinach crop was analyzed using PROC GLM. Least-squares means analysis at  $P \le 0.05$  was used for mean separation. To stabilize variances, arcsine square root or  $\log(x + 1)$  transformations were used. Back-

transformed means are reported throughout the article.

#### RESULTS AND DISCUSSION

Initial weed densities before treatment applications were three to four times higher in iterations 2 (291 weeds/m<sup>2</sup>) and 3 (272 weeds/m<sup>2</sup>) than in iteration 1 (72 weeds/m<sup>2</sup>). Hairy nightshade (Solanum sarrachoides Sendtn.) was the dominant weed in iteration 1, comprising 57% of the population. The dominant species in iteration 2 was burning nettle (Urtica urens L.), comprising 47% of the population. No weed species dominated in iteration 3, with shepherd'spurse [Capsella bursa-pastoris (L.) medik] (26% of the population), hairy nightshade (22% of the population), and chickweed [Stellaria media (L.) Vill.] (29% of the population) as the most common species. Most weed species in all iterations were broadleaves, which may be easier to manage than grass weeds with stale seedbeds (Caldwell and Mohler 2001).

The rototiller-bed shaper combination achieved 100% broadleaf weed control in all iterations (Table 1). Although effective, the bed shaper may not be the most appropriate implement to form stale seedbeds because (1) it is more expensive to operate and maintain than the rotary hoe and rolling cultivator with top knives, and (2) it causes high levels of soil disturbance that may reduce soil aggregate size and stability, increase organic carbon losses (Elliott and Efetha 1999; Pagliai et al. 2004; Pinheiro et al. 2004), and bring new weed seeds into the germination zone.

The rotary hoe consistently removed at least 97% of all broadleaf weed species at the cotyledon to oneleaf growth stage (Table 1). At the two- to four-leaf stage, the rotary hoe provided 63% control, which was less than all other treatments except the clove oil (Table 1). Others have reported weed control levels of 70 to 80% with the rotary hoe (Buhler et al. 1992; Lovely et al. 1958). The rotary hoe is most effective when the weed seeds have germinated but not yet emerged, or when the weeds are very small (Gunsolus 1990; Oriade and Forcella 1999). Delaying rotaryhoeing until weeds emerge can reduce effectiveness (Lovely et al. 1958), and may be why the rotary hoe was less effective on purslane (Portulaca oleracea L.) and volunteer rye (Secale cereale L.) than other cultivation implements in iteration 1 in this study (Table 1).

<sup>\*</sup>SAS, Statistical Analysis System Software, Version 9.1, SAS Institute Inc., SAS Campus Drive, Cary, NC 27513-2414.

Table 1. Percentage of weed control by various stale seedbed techniques in the three experimental iterations before planting. a.b

Species	Bed shaper <sup>c</sup>	Flamer	Clove oil	Rotary cult.	Rotary hoe	Top knives			
Iteration 1									
SOLSA	100	75 ab	40 c	90 a	63 bc	87 ab			
POROL	100	76 a	8 c	78 a	39 b	67 a			
CAPBP	100	100 a	100 a	100 a	100 a	100 a			
Broadleafd	100	89 a	36 c	89 a	63 b	87 a			
SECCE	100	100 a	8 c	71 b	11 c	82 b			
Iteration 2									
URTUR	100	65 b	100 a	99 a	100 a	97 a			
POROL	100	36 c	100 a	75 b	100 a	97 a			
MALPA	100	67 c	86 ab	76 bc	97 a	72 bc			
Broadleaf	100	72 b	95 a	97 a	99 a	96 a			
SECCE	100	59 b	64 b	65 b	62 b	95 a			
Iteration 3									
SOLSA	100	91 b	99 a	99 a	99 a	94 b			
POROL	100	82 b	96 a	100 a	100 a	98 a			
CAPBP	100	55 b	100 a	100 a	100 a	97 a			
STEME	100	100 a	94 c	100 a	99 ab	98 b			
Broadleaf	100	86 c	97 b	99 a	99 a	96 b			
SECCE	100	47 c	15 d	85 a	70 b	71 b			

<sup>&</sup>lt;sup>a</sup> Abbreviations: cult., cultivator; SOLSA, hairy nightshade; POROL, *Portulaca oleracea* L., common purslane; CAPPB, shepherd's-purse; SECCE, *Secale cereale* L., rye; URTUR, burning nettle; MALPA, *Malva parviflora* L., little mallow; STEME, common chickweed.

Total broadleaf weed control with clove oil in iteration 1 was the least effective (36%) of all treatments (Table 1) and was especially ineffective on purslane with only 8% control. Poor purslane control at the low rate may be due to the waxy cuticle of this species. However, clove oil controlled 95 to 97% of all broadleaves in iterations 2 and 3. Greater control can be attributed to the smaller weed size and the higher concentration used. Clove oil did not control volunteer rye. The difference between broadleaves and grasses partially occurs because clove oil is a contact herbicide, and the growing point for broadleaf weeds is aboveground, whereas the growing point for grasses remains belowground in the early growth stages.

Broadleaf weed control with the flamer at 24 kg/ha of propane ranged between 72 and 89% (Table 1). The flamer achieved significantly less control of total broadleaves than all other techniques in iterations 2 and 3 but significantly greater control than clove oil and the rotary hoe in iteration 1. Ascard (1995) achieved complete control of some weed species with unprotected growing points (i.e., chickweed) in the zero- to four-true-leaf stage at propane doses of 20 to 50 kg/ha and found that complete control of species with protected growing points (i.e., shepherd's-purse) was only achieved at very early growth stages. Ascard

(1994) also reported 95% control with 40 kg/ha of propane on weeds with zero to two leaves, but later growth stages required approximately 70 kg/ha to achieve similar control levels. In iteration 1 of our study, the flamer controlled 100% of the shepherd'spurse and rye seedlings, and 75 to 76% of the seedlings of the remaining weed species when applications were made at the two- to four-leaf stage (Table 1). Control of weeds in the cotyledon to oneleaf growth stage in iterations 2 and 3 varied by species ranging from 36 to 100%. The flamer is an effective weed management implement on small broadleaf weeds but may be less effective on grasses due in part to the location of the growing point (Ascard 1995). Ascard (1995) found that annual bluegrass (Poa annua L.) was difficult to control with a flame weeder regardless of application rate or weed developmental stage.

No weeds emerged following spinach planting in iteration 1. The lack of weed emergence is attributed to insufficient soil moisture. In iteration 2, total weed emergence was greater following simulated planting than emergence with the initial preirrigation (data not shown). Two species, chickweed and bluegrass that are typically winter annual weeds in the central coast of California, only germinated following simulated planting and accounted for the majority of the

<sup>&</sup>lt;sup>b</sup> Mean separations within rows by least-squares means, P < 0.05.

<sup>&</sup>lt;sup>c</sup> Weed control in all plots with the bed shaper was 100% with zero variance. Therefore, the data for the bed shaper were removed from the analysis.

<sup>&</sup>lt;sup>d</sup> The total of all broadleaved weeds counted at each site.

Table 2. In-crop emergence of individual weed species, total in-crop weed emergence (emergence), and in-crop weed emergence plus weeds that survived the stale seedbed techniques (emerg. + surv.) as affected by various weed control techniques in iterations 2 and 3.a.b

	Bed shaper	Flamer	Clove oil	Rotary cult.	Rotary hoe	Top knives		
	weeds/m <sup>2</sup>							
Iteration 2								
URTUR	70 b	42 c	32 c	74 ab	112 ab	216 a		
MALPA	2 b	4 ab	5 a	5 a	3 ab	10 a		
Emergence <sup>c</sup>	95 a	54 b	50 b	94 a	142 a	250 a		
Emerg. + surv.c	95 b	117 ab	56 c	107 ab	143 ab	272 a		
Iteration 3								
SOLSA	6 a	0 c	0 c	4 b	3 bc	2 c		
STEME	53 a	21 d	23 cd	54 ab	70 a	42 bc		
CAPBP	55 a	10 c	6 c	48 b	41 b	49 ab		
Emergence <sup>c</sup>	125 a	44 b	35 b	114 a	123 a	102 a		
Emerg. + surv.°	125 a	76 b	43 c	115 a	124 a	113 a		

<sup>&</sup>lt;sup>a</sup> Abbreviations: URTUR, burning nettle; MALPA, little mallow; SOLSA, hairy nightshade; STEME, common chickweed; CAPBP, shepherd's-purse.

increase in weed numbers. Both species exhibit annual fluctuations in dormancy levels, and in iteration 2, it is likely that the initial preirrigation occurred when the majority of the seed bank for these two species was dormant (Shem-Tov and Fennimore 2003). However, 14 d later when the plots were irrigated after simulated seeding, a large population of chickweed and bluegrass seeds was no longer dormant, and they emerged. This illustrates the importance of timing when using stale seedbeds. However, we did not include the chickweed and bluegrass counts in iteration 2 because they were not present when we tested the various techniques, and including them would mask treatment effects on species that were present when the stale seedbed techniques were applied.

In this study, weed control levels achieved with the two "no-disturbance" techniques (herbicide and flamer) were often lower than the weed control levels achieved with those techniques that disturbed the soil. However, in-crop weed emergence was significantly lower with the no-disturbance treatments vs. the "disturbance" treatments (Table 2). The number of weeds in the crop (including weeds germinating in the crop and those that survived control) 21 d after planting (or simulated planting) was significantly lower in the clove oil treatment in iteration 2 and significantly lower in both the flamer and clove oil treatments in iteration 3 in comparison to all other treatments (Table 2). We are uncertain if the lower weed numbers in the crop following stale seedbed formation with the flamer or the clove oil will significantly affect in-crop weed control costs when compared with higher weed numbers after stale seedbed formation using shallow tillage implements.

The rotary cultivator, rotary hoe, and top knives were the fastest techniques with the lowest labor costs, whereas the bed shaper was the slowest technique

Table 3. Estimated cost of stale seedbed treatments using different implements for weed control.<sup>a</sup>

Time	Equipment <sup>b</sup>	Material <sup>c</sup>	Equipment <sup>d</sup>	Labor <sup>e</sup>	Total		
hr/ha	\$/hr	\$/ha					
0.80	22.32	0	17.86	11.05	28.91		
0.64	20.79	21.00	13.31	8.86	43.17		
0.70	22.17	1,347.00	15.52	9.69	1,372.21		
0.36	24.37	0	8.77	4.97	13.75		
0.34	24.75	0	8.41	4.70	13.11		
0.28	20.87	0	5.85	3.88	9.73		
	hr/ha 0.80 0.64 0.70 0.36 0.34	hr/ha \$/hr  0.80 22.32  0.64 20.79  0.70 22.17  0.36 24.37  0.34 24.75	hr/ha \$/hr  0.80 22.32 0  0.64 20.79 21.00  0.70 22.17 1,347.00  0.36 24.37 0  0.34 24.75 0	hr/ha \$/hr	hr/ha \$/hr \$/ha \$/ha \$/ha \$/ha \$/ha \$/ha \$/ha \$/ha		

<sup>&</sup>lt;sup>a</sup> All calculations derived from cost–return studies produced at the University of California, Davis (Tourte et al. 2004). The total cost does not include the cost of applying 7.6 cm of irrigation water (\$185.32/ha).

<sup>&</sup>lt;sup>b</sup> Mean separations within rows by least-squares means, P < 0.05.

<sup>&</sup>lt;sup>c</sup>Includes broadleaves and grasses.

<sup>&</sup>lt;sup>b</sup> Includes cost of operating implement and tractor.

<sup>&</sup>lt;sup>c</sup> Based on the current cost of propane (\$1.63/gal) and herbicide mix (Matran II at \$72.35/gal mixed with Integrate at \$19.50/gal).

<sup>&</sup>lt;sup>d</sup>Cost of owning and running the equipment.

<sup>&</sup>lt;sup>e</sup>Assuming a salary of \$13.84 per hour.

with the greatest labor costs (Table 3). The herbicide was the most-expensive technique at \$1,372/ha. The flamer, rotary cultivator, rotary hoe, and top knives were the least-expensive techniques ranging from \$10 to \$43/ha. The flamer cost \$29 to \$33/ha more than the least-shallow tillage implements but generally had fewer weeds in the crop, including those that survived the stale seedbed preparation and those that emerged later. The current cost of the clove oil herbicide makes its use prohibitive for most situations.

A variety of organic-compliant techniques may be used effectively to form stale seedbeds. Techniques that do not disturb the soil surface generally have fewer weeds germinating with the crop. The appropriate implement may vary between growers, and should be selected based on operating cost, on-farm availability, and efficacy. Additional research to examine the potential of double preirrigation to control multiple weed flushes, construction of emergence models (degree–days) to time operations to coincide with maximum weed emergence, and determination of soil moisture levels needed to maximize weed emergence would lead to improved implementation of stale seedbeds.

## LITERATURE CITED

- Ascard, J. 1994. Dose–response models for flame weeding in relation to plant size and density. Weed Res. 34:377–385.
- Ascard, J. 1995. Effects of flame weeding on weed species at different developmental stages. Weed Res. 35:397–411.
- Buhler, D. D., J. L. Gunsolus, and D. F. Ralston. 1992. Integrated weed management techniques to reduce herbicide inputs in soybean. Agron. J. 84:973–978.
- Buhler, D. D. and T. C. Mester. 1991. Effect of tillage systems on the emergence depth of giant (*Setaria faberi*) and green foxtail (*Setearia viridis*). Weed Sci. 39:200–203.

- Caldwell, B. and C. L. Mohler. 2001. Stale seedbed practices for vegetable production. Hort. Sci. 36:703–705.
- Cousens, R. and S. R. Moss. 1990. A model of the effects of cultivation on the vertical distribution of weed seeds within the soil. Weed Res. 30:61–70.
- du Croix Sissons, M. J., R. C. Van Acker, D. A. Derksen, and A. G. Thomas. 2000. Depth of seedling recruitment of five weed species measured in situ in conventional and zero-tillage fields. Weed Sci. 48:327–332.
- Elliott, J. A. and A. A. Efetha. 1999. Influence of tillage and cropping system on soil organic matter, structure and infiltration in a rolling landscape. Can J. Soil Sci. 79:457–463.
- Gunsolus, J. L. 1990. Mechanical and cultural weed control in corn and soybeans. Am. J. Altern. Agric. 5:114–119.
- Johnson III, W. C. and B. G. Mullinix Jr. 1995. Weed management in peanut using stale seedbed techniques. Weed Sci. 43:293–297.
- Johnson III, W. Č. and B. G. Mullinix Jr. 1998. Stale seedbed weed control in cucumber. Weed Sci. 46:698–702.
- Johnson III, W. C. and B. G. Mullinix Jr. 2000. Evaluation of tillage implements for stale seedbed tillage in peanut (*Arachis hypogaea*). Weed Technol. 14:519–523.
- Lovely, W. G., C. R. Weber, and D. W. Staniforth. 1958. Effectiveness of the rotary hoe for weed control in soybeans. Agron. J. 50:621–625.
- Mohler, C. L. and A. E. Galford. 1997. Weed seedling emergence and seed survival: separating the effects of seed position and soil modification by tillage. Weed Res. 37:147–155.
- [NASS] National Agricultural Statistics Service. 2005. Vegetable 2004 Summary. U.S. Department of Agriculture: Web page: http:// usda.mannlib.cornell.edu/reports/nassr/fruit/pvg-bban/. Accessed: July 1, 2005.
- Oriade, C. and F. Forcella. 1999. Maximizing efficacy and economics of mechanical weed control in row crops through forecasts of weed emergence. J. Crop Prod. 2:189–205.
- Pagliai, M., N. Vignozzi, and S. Pellegrini. 2004. Soil structure and the effect of management practices. Soil Tillage Res. 79:131–143.
- Pinheiro, E. F. M., M. G. Pereira, and L. H. C. Anjos. 2004. Aggregate distribution and soil organic matter under different tillage systems for vegetable crops in a Red Latosol from Brazil. Soil Tillage Res. 77:79–84.
- Shem-Tov, S. and S. A. Fennimore. 2003. Seasonal changes in annual bluegrass (*Poa annua*) germinability and emergence. Weed Sci. 51:690–695.
- Tourte, L., R. F. Smith, K. M. Klonsky, and R. L. De Moura. 2004. Sample costs to produce organic leaf lettuce. Central coast region, Monterey and Santa Cruz counties. Davis, CA: University of California Cooperative extension publication LT-CC-04-O. Pp. 1–18.
- Yenish, J. P., T. A. Fry, B. R. Durgan, and D. L. Wyse. 1996. Tillage effects on seed distribution and common milkweed (*Asclepias syriaca*) establishment. Weed Sci. 44:815–820.